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METHOD FOR COLLECTIVELY MAKING MICRORELIEFS, AND ESPECIALLY MICROPRISMS BY MICRO-MACHINING AND TOOLS FOR IMPLEMENTING THE METHOD.

Technical field and prior art

The invention concerns machining of miniaturized components, for example micro-optical components.

In particular, it concerns a method and a device for collectively making microreliefs and especially microprisms by micro-machining.

The invention is thus related to the fields of microcomponents, components for micro-optics, microlasers or solid waveguide amplifiers pumped by diodes. It concerns generally microtechnology.

Micro-optical components are used for applications in military and civil optics or optronics (telecommunications, industries for mass-consumption products : "compact disc", video devices…), which require that components and systems be miniaturized and this for economical and/or technological reasons. These components may be collectively obtained through lithographic and/or etching techniques for optical or optronic material, whether doped or not, like silica or other crystalline materials such as lithium niobate or tantalate ($LiNbO_3$ or $LiTaO_3$) or even polymers or new organic materials.

Microlasers and waveguide amplifiers are monolithic solid lasers of small dimensions pumped by laser diode. Their main advantage is their structure, which consists in a stacking of multilayers for which collective manufacturing methods of the type used in micro-electronics may be applied. Thus, it is possible to make reliable components by using a mass production

technology, potentially at a very low cost (as in micro-electronics).

Microlasers are described for example in the article by N. Mermilliod et al, published in Applied Physics Letters, Vol. 59, No. 27, p. 3519 (1991).

Others microlasers are described in document EP-653 824.

For certain microlasers or in waveguide amplifiers, the laser beam is not transmitted perpendicularly to the substrate's plane, but parallel to the latter (parallel to the waveguide). For proper operation of the laser or the amplifier, machining the side faces is therefore attempted in order to obtain very good parallelism between them, and low roughness (a polished condition) on each of them. In certain cases, it may be worthwhile to send back the beam vertically or perpendicularly to the plane of the substrate, as in the case of vertical cavity lasers (VCSEL). A technological solution consists then, as illustrated in Fig. 1, of positioning a micromirror 2 at 45° facing the output beam 4 of the laser or of the guide 6. Also, it may be interesting to position a micromirror at the input of a microlaser device.

Furthermore, it may be appropriate, for certain types of microlaser cavities, to collectively manufacture microprism structures directly in a laser or electro-optical material; this is the case for a pulsed microlaser cavity with active triggering by a micromodulator, such as described in application EP-751 594.

Finally, manufacturing microprisms in a laser material may prove to be necessary for making minilasers with transverse pumping, Fig. 2 is a

reminder of its operating basics: a pumping beam 8 enters the microlaser or laser cavity by an input mirror 10, and pumping the laser active medium 12 gives rise to a laser oscillation 14 which will result in a laser beam 16 transmitted through and output mirror 18. The beam oscillates in the cavity between the output mirror 18 and a microprism 20 at the bottom of the cavity.

For all these components, the issue is how to build these microprisms.

Two techniques for making microprisms of any geometry are known.

The first technique is described in document WO 96/05525. This is a method which may be described as "pseudo-collective", as it provides collective processing, during the manufacturing steps, of components, the blanks of which are pre-assembled one by one.

The steps of this technique are summarized in Figs. 3A-3D. A wafer 22 of material for microprisms (for example: (silica) is cut out into arrays 24, 26 of chips which are then mounted as blocks for blank-forming and polishing the inclined faces. This assembly (Fig. 3C) is carried out on a support 30, inclined with the angle α of the desired prism, a shim 28 for glueing and a support 32 for glueing. After glueing, support 32 and shim 28 are removed.

Then, by using a polishing support 34, the arrays 24, 26 are formed then polished on one face and if necessary on the other face (Fig. 3D).

These operations are essentially manual operations, and they require many substeps for mounting and dismounting which prove to be generally expensive.

Moreover, this method may prove to be not very reliable because controlling the angles from one part to another depends on a great number of parameters which are themselves badly controlled, such as for example, the thickness of the adhesive film required for fixing on support 30.

And, above all, this method does not allow a substrate to be globally processed like a microprism wafer, for integration in an actual microsystem with for example a complementary structure, the unit patterns of which would be collectively self-aligned (plate to plate).

The second technique is based on a technology of the micro-electronic type and is described in document JP-59 139002. In this case, dies for replication and microprisms are made by lithography and etching of a multilayer structure. Practically, it consists in depositing at least two silica layers by a "CVD" (chemical vapor deposition) technique, and in controlling their respective etching rates by the annealing temperature for each layer (from 700 to 1000°C). The etching rate of the upper layer(s) should be higher than that of the lower layer(s). Thus, by reactive chemical etching (RIE) through the ports of the upper mask, pyramidal structures are obtained, the angle of which may be controlled for making microprisms.

This technique is collective since mask lithography is performed. However, it is relatively "unwieldy" (it requires several levels of annealing and etching), so it is expensive. Furthermore, it is "indirect", because first it requires dies to be built and then structures to be replicated. Finally, the thickness of the

structures, i.e. the vertical dimensions of the optically used areas, seems to be rather limited by the performances within the reach of present coating and etching methods (from a few microns (µm) to a few tens of microns).

In integrated optics, in the field of waveguides, which are desirably coupled with an optical fiber, the issue is the quality of the coupling between the input, or the output of the guide and the fiber.

To obtain low optical losses, the aim is to have low roughness of the surfaces to be brought into contact. Generally, it is not possible to directly obtain the adequate roughness at the end of guide with standard micro-cutout methods. For instance, in the case of integrated optics on silicon, presently the most performing solution consists in cleaving the substrate, the active silica layer is "broken" in the extension of the cleavage, and the silica's surface condition obtained at the end of the guide is excellent. The problem is that the position of the cleavage with respect to the integrated device on the chip is not properly under control, so this reduces the manufacturing yield for the components and so manufacturing costs increase.

Document EP-532 229 describes an aligned cutout method followed, in the same operation as the cutting out, by polishing of the end of the guides by means of a diamond saw blade. With this technique, it is possible to both obviate the positioning problem and obtain a good surface condition at a low cost.

More recently, H. Yokosuka et al (1996, Electronic Components and Technology Conference, p. 487-493) have described an alternative to this method, which uses a

separate abrasive from that of the saw blade, during the cutting out. With this approach, the finished polished condition of the ends of the guides, cut in such a way, may be considerably improved, and therefore the guides' performances.

The above examples, show the technical problems which generically occur during collective or automated manufacturing of miniaturized "optical" microreliefs, whether assembled into microsystems or not.

Techniques for obtaining polished surfaces of laser microcomponents and machined micro-optical surfaces, as for example machining and polishing the faces of a microprism at 45° made of silica or of a lasing material (for making a "vertical" back-reflecting mirror for the input and/or output faces of a microlaser or a waveguide amplifier), resort to a succession of steps for blank-forming, cutting out, grinding and polishing which require a large number of substeps for preparing the samples to be processed. Furthermore, the sequencing of the steps cannot be considered as a true collective technique, because, at the best, the different microcomponents may only be processed by arrays which must be brought back onto a support in order to perform a given step. Now, in certain cases, it is even necessary to deal with the making of components on a wafer basis, in order to bring back the whole set of components in one single block onto another substrate containing additional elements of the system or of the miniaturized device.

Description of the invention

The invention provides an original solution to the problems because it enables the structure to be

machined before the cutting out and optionally the active surface(s) to be polished, in one or more sequenced steps without mounting and dismounting the microcomponents or the arrays. These operations may be performed by an automatic machine and by implementing this technique, manufacturing costs may be lowered and/or integration possibilities may be increased, and/or global component reliability may be improved.

The object of the invention is a method for making, in a substrate, microcomponents exhibiting microreliefs, consisting of:

- a first step for making the desired microrelief by machining the substrate, and
- simultaneously with the first step or after the latter, a second step for cutting out the microcomponents in the substrate.

Therefore the invention concerns the manufacturing of microreliefs before cutting out the components. The unit components are cut out in the wafer during a subsequent step to the machining and finishing operation(s), by using a cutting tool, for example, a standard tool, like a diamond saw blade.

It is understood that "microrelief" refers to any geometrical structure in three dimensions obtained by rectilinear machining of a substrate, or of one or more layers deposited on this substrate.

This so-called rectilinear machining is carried out in this case, by machining in only one direction located in the plane of the substrate.

The first machining step may comprise two substeps: a blank-forming substep and a finishing substep.

The microrelief may be made with only one tool moving at the surface of the substrate, or with several

tools acting simultaneously or in succession.

The vertical dimensions of the microreliefs are e.g. of the order of a few tens of microns (for example: 10 µm or 20 µm or 50 µm) to several hundreds of microns (for example: 200 µm or 400 µm or 600 µm).

A microrelief may be, for example, a microprism or micromirror structure for which the required surface condition after machining is said to be "optically" polished (low roughness: about 1 µm PV ("Peak to Valley"), i.e. 100 nm RMS (quadratic mean)). This surface condition may be obtained in the same operation as the blank-forming machining or in a second finishing step associated with the first step.

Accordingly, the invention in particular, concerns a collective (or automated) manufacturing process, which allows for collective machining, in a substrate or in one or more layers deposited on the substrate, of microreliefs (for example microprisms or micromirrors) with an "optically" polished surface condition (low roughness), in the same operation as for the machining of the component or of the structure, or in a second finishing step associated with a first blank-forming step.

For example, an abrasive blade with a "V" profile is applied for making a microprism.

A microprism may be defined as a microrelief with a prismatic structure (with one or more inclined faces), for example, for optical applications; it is then used, in this case, for its reflection (mirror) or transmission (dioptre) properties on the machined surfaces, with an "optical" polish quality.

This surface quality is to be understood as having low roughness as visually defined either by a mirror

finish condition which provides "good" reflection of light (with a relatively low optical loss rate), or by a transparent condition (a relatively low optical loss rate by transmission).

Brief description of the figures

Anyway, features and advantages of the invention will be more apparent in the light of the description which follows. This description deals with exemplary embodiments, for explanatory and non-limiting purposes, with reference to the appended drawings wherein:

-Fig. 1 illustrates a microlaser structure associated with a micromirror.

-Fig. 2 illustrates a minilaser structure with transverse pumping.

-Figs. 3A-3D illustrate steps of a method for making microprisms.

-Fig 4 illustrates an actively triggered microlaser structure;

-Figs. 5A-5E illustrate an embodiment of a method according to the invention for making actively triggered microlasers.

-Figs. 6A-6C are various shapes of feasible cuts within the framework of a method according to the invention.

-Fig. 7 is an exemplary embodiment of microprisms or micromirrors according to the invention.

-Figs. 8A and 8B illustrate the making, according to the invention, of microcomponents, each including a microlaser and a back-reflecting micromirror.

Detailed description of embodiments of the invention

A first exemplary embodiment of the invention will

be given: it deals with making microlasers with active triggering.

Structures for microlasers with active triggering are reported and described in document EP-724 316.

One of these structures is illustrated in the enclosed Fig. 4, in which reference symbol 42 refers to the active lasing medium and reference 44 to a triggering material, for example an electro-optical material such as $LiTaO_3$.

The active medium 42 of the laser forms a first Fabry-Pérot cavity with an input mirror 46 and an intermediate mirror 48. The triggering material forms a second Fabry-Pérot cavity, with the intermediate mirror 48 and the output mirror 50. For instance, the triggering material 44 may be bonded to the surface of the intermediate mirror 48. Both cavities are coupled. Triggering is performed by changing the optical length of the triggering material 44 through an external effect. If L_1, n_1, λ_1 (L_2, n_2, λ_2) designate the lengths, optical indices and optical resonance wavelengths of the first cavity (of the second cavity, respectively), the relationship holds: $m_1\lambda_1=2n_1L_1$ and $m_2\lambda_2=2n_2L_2$ with m_1 and m_2 as integers.

If material 44 is an electro-optical material, the triggering electrodes 52, 54 are placed perpendicularly to the axis of the laser beam 56 on both sides of the triggering material 44. If a voltage V is applied between these electrodes, this results in a electrical field $E=V/e$, where e is the distance between the electrodes (which corresponds to the thickness of the electro-optical material). Optical index n_2 and therefore optical length n_2L_2, of the electro-optical material is changed by the effect of the field E. This

affects coupling of both cavities and changes the reflectivity of the intermediate mirror 48 as seen by the lasing medium. Indeed, if resonance wavelengths of both cavities coincide ($\lambda_1=\lambda_2$ or $n_1L_1/n_2L_2=m_1/m_2$) the reflectivity of the second cavity (electro-optical) seen by the first cavity (laser material) will be minimum and there will be no laser effect.

Thus, by acting on the field E, resonance conditions for the microlaser may be changed, including the reflectivity of the second cavity and so active triggering may be achieved.

The steps for a method embodied according to the invention are illustrated in Figs. 5A-5E.

Fig. 5A shows the assembly of a wafer 60 of laser active material (examples of such materials are given in document EP-653 824) and of a wafer 62 of a electro-optical material (for example $LiTaO_3$).

Next, (Fig. 5B) the wafer is fixed on a self-adhesive plastic film 64, the thickness of which may be selected and the glue's adhesive properties may be adjusted by exposure to UV radiation. The whole is then fixed on a metal frame 66 which allows it to be handled. This frame is fixed on a cutting machine, for example via a machine surfaced suction support.

This machine additionally comprises a blade or an abrasive disc 68 as well as means 70 for driving the latter into rotation.

The selected blade here has plane and parallel faces, for machining vertical cuts 70, 72, 74. This blade may be a diamond saw, used as a grinder for blank-forming and polishing structures.

Next, the machine parameters are adjusted (the speed of rotation of the blade, the feedrate into the

material, the cutting depth) according to the type of blade used (type of die in which are embedded abrasive grits (diamond or other material), particle size and density of this abrasive, …).

In certain cases (especially for the hardest materials), the method is divided into at least two steps:

- a first blank-forming step, followed (with feature alignment):
- at least one finishing or polishing step, generally with finer abrasive grits.

The two step method may be carried out in a single pass by using a machine with dual spindle, the first mounted with the blank-forming blade, and the second with the finishing blade. To refine the surface condition and the defects in the material induced by machining, it is possible to use a cutting lubricant, mixed with the blade's cooling water or distributed separately. In Fig. 5B, a duct 75 is for bringing cooling fluid to the blade, for example water, with or without lubricant.

After this step, a machined structure is obtained, as illustrated in a top view in Fig. 5C.

A subsequent cutting step along a direction perpendicular to the direction of the cuts 70, 72, 74 (Fig. 5D) provides insulation of the individual chips 76 of the actively triggered microlaser (Fig. 5E). For example, each chip may assume a "T" shape which enables both the active width of the electro-optical cavity to be defined and the electrical contacts to be placed and tapped on each of the active faces 77, 79.

The parameters of the method, which depend on the machine, the blade and the operating conditions are

specifically determined for each type of application (dimensions of the microreliefs) and according to the nature of the material making up the prisms or the reflecting faces to be machined.

As an example for "sawing-polishing" of LTO (lithium tantalate) structures for making microlasers triggered by an external control voltage (as described above), the following parameters were selected:

- Speed of rotation of the blade: 20000 rpm.
- Feedrate for the blade: 0.5 to 1 mm/s.
- Maximum pass depth: 0.1 mm.
- Blade type: resin type die Ref. Thermocarbon: 2.25-6A-3XQ-3
- Cooling of the blade: deionized water (without any lubricant).

The observed appearance of the flanks of the output patterns is glossy and transparent, which correspond to a condition commonly designated as "optical" finish. flanks optical Roughness as measured by an interferometric microscope of the Micromap brand, on a field of about 100x100 µm² with a spatial resolution of about 0.5 µm, is of the order of 1 nm RMS (quadratic mean) and of 100 nm P-V (Peak to Valley: maximum amplitude shift).

Under these process conditions, the condition of the surface obtained on the electro-optical material is of the "optical" finish type, i.e. the material's machined flanks exhibit a transparent and glossy spectrum with a roughness of about 15 Å RMS.

The above described method may be adapted to other cutout forms and to other materials. In particular, the saw blades may be either with plane and parallel faces, for example for machining vertical cuts (Fig. 6A), or with one or two inclined faces with a predetermined

angle for machining inclined cuts for which the profile is illustrated in Fig. 6B. With the combination of these two types of blades, beveled cuts may be obtained for example with a profile as illustrated in Fig. 6C. Similarly, by combining orthogonal features (or cuts) or of any angle, reliefs of different, for instance pyramidal structures, may be obtained.

In particular, for making microprisms, diamond saw blades with a "V" profile shall be used as grinders for blank-forming and polishing the structures.

Through this technique, by using diamond saw blades which have a controlled angular bevel at the end of the blade, blanks for 90° microprism structures may be made in massive silica substrates. The possibility of controlling the angle to at least within 0.1° was checked with a profile projector.

Fig. 7, wherein identical references to those in Figs. 5A-5B designate identical or matching elements, is an example of "sawing-polishing" of microprism structures 80 or micromirror structures 82 on a substrate 84. The blade 78 used has a truncated "V" profile, exhibiting a plane surface 86.

Fig. 8A, wherein identical references to those of Figs. 5A-5B designate identical or matching elements, illustrates the making principle according to the invention of microprisms for collectively manufacturing chips for a microlaser waveguide associated with a micromirror for reflecting back the beam.

A plate of active lasing material 92, associated with a substrate 90, is machined by using two blades 88, 98 which for example, operate in parallel. The first one, defines a back reflecting micromirror 100, facing each laser emitter 102, whilst the second blade

separates each microlaser component (with its back reflecting mirror) from the neighboring components (each is associated with its own back reflecting mirror). Each individual component may then emit a beam 104 as illustrated in Fig. 8B.

An alternative to the above described method, consists of making a blank, as described earlier and on completion of finishing (or of polishing), of using a blade or a grinder, without any bound abrasive grits in the die, and of using this blade as a carrier of a separate polishing abrasive distributed along the blank feature. In this case, the blade without any diamond die, acts as a polishing support by drawing the abrasive grits into each of its flanks, through its rotation. The width of the blade is adjusted according to the width of the blank feature and of the particle size of the used abrasive (the width of the finishing blade is selected so as to be smaller than the width of the blank feature). The structure of the blade may be grooved or not.

The abrasive may be distributed either along the blank feature, by blasting it instead of the blade's cooling water, as a liquid solution, or it may cover for example the blank-formed wafer, as a liquid, a gel, or as a more compact paste. The nature of this abrasive (alumina, cerium oxide, diamond, silicon or boron carbides …), depends on the required hardness and surface condition for a given application and a type of material to be machined.

A second alternative to the method may be implemented after the first blank-machining step, and instead of or in addition to the surface finishing step, by proceeding with chemical etching on the

surface or with a planar coating (for example: a metal layer or dielectric multilayers), according to technological characteristics and specifications for the device.

A third alternative to the method consists in using a "U" blade, the end of which is bound with abrasive grits, and the side part (with parallel faces) is bound with an abrasive of a lower particle size. This type of blade provides faster blank-forming (due to the large grit) and finishing in the same feature, on the active side faces.